

U.S. research enterprise and to U.S. national interests more broadly:

The nature of science is international, and the free flow of people, ideas, and data is essential to the health of our scientific enterprise. Many of the scientific challenges, for example in health, environment, and food, are global in scope and require on-site cooperation in many other countries. In addition to scientific benefits, collaborative scientific and engineering projects bring Nations together thereby contributing to international understanding, good will, and sound decision-making worldwide (Clinton and Gore 1994, 8).

Advances in Science and Engineering

NSF funding of basic research across a broad range of disciplines as well as funding from other government agencies, industry, and academia in the United States and abroad has led to many advances. Science and engineering breakthroughs have contributed to new capabilities in equipment that subsequently have enabled newer discoveries. It is not possible to review them all. The following discussion will be only illustrative in nature and will point to other ongoing efforts to identify and document such advances.

Central to the vision of the first transition period was the desirability of encouraging and facilitating partnerships among the three primary sectors of the U.S. research community: academia, industry, and government. Although the relationships among these sectors have changed considerably since that time, these partnerships have been essential to the major advances in all fields of science and engineering that have taken place during the past 50 years. These advances have led us to a better understanding of ourselves and the world around us. Increased understanding has, in turn, underlain the development of new products and processes, which have changed our everyday lives and the way we live them. Deeper understanding of specific aspects of the natural and human-influenced world has also demonstrated how little we know in many cases and suggested the need for new approaches to address important scientific and engineering problems. This finding has led to increased multidisciplinary research, international and intersectoral cooperation, and the creation of disciplines and whole industries (for example, information technology and biotechnology industries) that did not exist during the first transition period. Such advances have changed our lives, our economy, and our society in important and sometimes profound ways.⁴⁶

The View by *Indicators*

Earlier editions of *Science and Engineering Indicators* reports have discussed important discoveries and advances. For example, the “Advances in Science and Engineering” chapter of *Science and Engineering Indicators – 1980* covered the following areas:

- ♦ Black Holes,
- ♦ Gravity Waves,
- ♦ The Sun,
- ♦ Cognitive Science in Mathematics and Education,
- ♦ Information Flow in Biological Systems,
- ♦ Catalysts and Chemical Engineering, and
- ♦ Communications and Electronics.

The *Science and Engineering Indicators – 1982* “Advances in Science and Engineering” chapter covered the following areas:

- ♦ Prime Numbers: Keys to the Code,
- ♦ The Pursuit of Fundamentality and Unity,
- ♦ The Science of Surfaces,
- ♦ Manmade Baskets for Artificial Enzymes,
- ♦ Opiate Peptides and Receptors,
- ♦ Helping Plants Fight Disease, and
- ♦ Exploring the Ocean Floor.

The *Science and Engineering Indicators – 1985* chapter entitled “Advances in Science and Engineering: The Role of Instrumentation” covered five case studies illustrating the important and synergistic roles that refinements in measuring and computing technologies play in undergirding and linking advances in science and engineering, as well as in developing new fields, processes, and products in academia and industry. The chapter highlighted the following areas:

- ♦ *Spectroscopy*—including a discussion of optical spectroscopy, mass spectroscopy, and nuclear magnetic resonance spectroscopy;
- ♦ *Lasers*—including discussions of applications in chemistry, measurement of fundamental standards, commercial applications, and biomedical applications;
- ♦ *Superconductivity*—including discussions of the fundamental process, the search for superconductors, applications, and ultra-high-field magnets;
- ♦ *Monoclonal Antibodies*—including the discovery of the technology, production of pure biochemical reagents, studies of cell development, potential medical applications, and engineered monoclonal antibodies; and
- ♦ *Advanced Scientific Computing*—assisting scientists and engineers to test ideas on the forces moving the Earth’s plates, track the path an electron takes within the magnetic fields of a neutron star, link a fragment of viral DNA to a human gene, watch plasmas undulating within fusion reactors yet to be built, form and reform digital clouds and monitor the formation of tornadoes, see galaxies born and watch their spiral arms take shape, set the clock at the (almost) very beginning and recreate the universe, begin

⁴⁶See “100 Years of Innovation: A Photographic Journey,” *Business Week*, Summer Special Issue 1999 for a remarkable essay of how science, technology, and innovation have changed our lives.

to think about confirming and denying the root theories of proton and neutron structure in order to test our ideas of the nature of matter, and predict how a spacecraft will glide through the atmosphere of Jupiter.

Some of the cutting-edge problems discussed in these earlier chapters remain current. Others have long since been resolved and are now regarded as commonplace. This illustrates the rapidly changing nature of discoveries in science and engineering as well as the difficulties in predicting what new advances will occur and when.

Contributions from the Past and Toward the Future

The basis for some of the advances of the past 50 years occurred during the first transition period. For example, the transistor was invented in 1947, ultimately leading to the invention of microchips in the 1960s. The Electronic Numerical Integrator and Computer, developed by University of Pennsylvania engineers, first became operational in 1948 and was the progenitor of several generations of computers, including the personal computer, first introduced in the 1970s. Information technologies resulted from the fusion of computer and communications technologies. Through information technologies, advances in materials science and physics have led, in turn, to new industries (see NRC 1999 and Huttner 1999), streamlined processes in traditional industries, and expanded scientific capabilities. (See chapter 9 for a discussion of the significance of information technologies.)

Scientists and engineers from all over the globe have joined together to explore space and our universe. Based on accomplishments over time from many countries, the United States was able to send a man to the moon and back in 1969 and a tiny Sojourner rover to Mars in 1997; both captured our imaginations and enhanced our understanding of our universe. Construction of an international space station is now under way with men and women contributing to its development and its associated missions.

The bases for many of the significant advances that have occurred since the late 1940s have been consistent with the importance of developing partnerships as well as the importance of encouraging individual researchers to pursue new and innovative ideas. In the area of medicine, the polio vaccine was developed in the 1950s by physician Jonas Salk, and microbiologist Albert Sabin later developed an oral vaccine. The first heart transplant was performed in 1967. Today many organs are being transplanted or replaced with artificial parts or organs, and researchers are making use of fundamental knowledge to investigate the role of genetics in preventative treatment for some diseases.

The double helical structure of the DNA molecule was discovered in the 1950s, and recombinant DNA techniques (or gene splicing) occurred in the early 1970s, leading to many additional advances. Researchers around the world are striving to complete the human genome project. Advances in a variety of subfields of the biosciences have resulted in vast

amounts of new data, leading to the problem of how to store, interpret, and make these data available to researchers in other subfields. Researchers in computer sciences and biological sciences have addressed this problem by creating the entirely new field of biological informatics, which applies advances in information technology to make possible further understanding of biological systems.

In plant biology, researchers currently apply genetic engineering to develop crops resistant to disease and insects. It is now known that all flowering plants derive from a common ancestry and share a common set of biochemical pathways. This knowledge has led plant biologists to direct their coordinated research efforts toward developing a complete understanding of a small, relatively simple flowering plant, *Arabidopsis*, that serves as a model organism. Scientists around the globe, in a multiagency, multinational project, are mapping and identifying the function and location of all the genes in *Arabidopsis*. New fundamental discoveries from this initiative have already led to significant improvements in several crop plants and may possibly result in totally new crops in the future. The *Arabidopsis* project is also providing information that can be used to study genes from a variety of more complex organisms, ranging from corn and wheat to mice and humans.

Breakthroughs are not without controversy. The cloning of Dolly the sheep, the first mammal to be cloned from an adult cell, has been a triumph and a concern. It is an example of the importance of dialogue with the public and better understanding of societal concerns. Findings in Chapter 8 on public attitudes and understanding of science and technology show that the public greatly appreciates scientific discoveries, although they do not always fully understand them. Also a large majority believe that in general the benefits of scientific research outweigh harmful results. Nonetheless, when asked about genetic engineering, the U.S. public's answers are more evenly divided.

Over the past half-century, discoveries associated with NSF funding⁴⁷ include materials science discoveries by engineers, chemists, physicists, biologists, metallurgists, computer scientists, and other researchers. These advances have led to increased data storage capacity of computer systems, advances in semiconductor lasers, improvements in compact disc players and laser printers, new medical applications, and major breakthroughs in synthetic polymers which are found today in products from clothing to automobiles.

Because of the complex nature of both research itself and its links to possible useful products and processes, there is often a delay between the dissemination of fundamental knowledge and its eventual outcome or effect on products or processes. Therefore it is not always easy to trace back to the precise origins of all discoveries. Nevertheless, a number of studies have accomplished this goal. For example, an early study contracted for by NSF, entitled *Technology in*

⁴⁷See *America's Investment in the Future*, an NSF publication in press, for an engaging and broad-ranging discussion of important discoveries made by researchers funded by NSF.

Retrospect and Critical Events in Science (Illinois Institute of Technology 1968; commonly known as the “Traces” study) chronicled and traced the development of important innovations such as magnetic ferrites, videotape recorders, the oral contraceptive pill, the electron microscope, and matrix isolation, an example of a scientific technique used in certain chemical processing industries. In most cases, the traces emphasized the importance of nonmission research and contributions from all sectors and their interplay. The study pointed out the importance of interaction between science and technology and interdisciplinary communication as well as demonstrated the long-term, sometimes serendipitous, nature of innovation. This social science study was a precursor to many of today’s efforts to trace innovations and conduct accountability studies such as called for under the Government Performance and Review Act (see chapter 2 for more explanation of this Act). Current studies and different approaches also demonstrate the close nature of science and technology to new products and processes (NSB 1998b; Narin, Hamilton, and Olivastro 1997).

A more traditional way of acknowledging important scientific discoveries and breakthroughs is with awards. The most famous scientific award is the Nobel Prize. Appendix table 1-1 lists the various Nobel Prizes since the 1950s and the accomplishments that they celebrate. An examination of the discoveries listed provides a glimpse into the progress in several fields.

Research is increasingly collaborative and interdisciplinary in nature. Findings from one country, discipline, or sector can build on those developed in others, highlighting the importance of alliances and partnerships. Chapters 2 and 6 show how such collaborative activities have increased over the past decade. As one important example of interdisciplinary research, computer scientists, mathematicians, and cognitive scientists have joined forces with scholars in the humanities to conduct research on modeling and visualization techniques to address a variety of problems from modeling the human heart or brain to modeling traffic patterns. Nanotechnology is another important emerging interdisciplinary field that has many potentially valuable applications. International cooperation has also increased considerably during the past 50 years, with many large-scale scientific projects planned and financed internationally from the outset.

With the help of ever more powerful instruments—be it the Hubble telescope or the new Gemini telescopes—astronomers and astrophysicists are increasing understanding of our solar system and even reaching beyond to discover planets outside of our solar system. An important recent example is the Gemini project, to construct and operate a pair of identical, state-of-the-art, 8-meter optical telescopes in the Northern and Southern Hemisphere (at Mauna Kea, Hawaii, and Cerro Pachon, Chile). Project Gemini is an international project involving the United States, the United Kingdom, Canada, Argentina, Australia, Brazil, and Chile. Gemini North has been dedicated and has provided some of the sharpest

infrared images ever obtained by a ground-based telescope. These first high-resolution images from Gemini North reveal the remarkable power of the telescope’s technologies, which minimize distortions that have blurred astronomical images since Galileo first pointed a telescope skyward almost 400 years ago. The clarity of these images is equivalent to resolving the separation between a set of automobile headlights at a distance of 2,000 miles.

Large-scale physics facilities such as Centre Européenne pour la Recherche Nucléaire and its Large Hadron Collider are also investigating the structure of our universe from the atomic to the cosmic scale in a fascinating and different fashion. The work of astronomers and physicists have created new knowledge about the infinite vastness and smallness of our marvelous universe. *Physics in the Twentieth Century* by Curt Supplee (1999) documents many of the important breakthroughs in physics, and the May 1999 issue of *Physics Today* heralds many of the triumphs in astronomy over the past 100 years.

Discoveries in the geosciences and engineering have enabled us to better prepare for and predict disasters such as earthquakes and to mitigate economic and social effects of long-term weather phenomenon such as El Niño. New discoveries related to plate tectonics and discoveries from interdisciplinary polar science research have increased our understanding of our world, its structure, and its atmosphere.

Advances in the social and behavioral sciences cannot be ignored and are key to solving and understanding some of our Nation’s and world’s most complex problems. Better understanding of economics and game theory, risk assessment, and cognitive science have made important contributions to our economy and well-being.

The Importance of Human Resource Development: The NSF Class of 1952

None of these advances could have been accomplished without the hard work of numerous talented scientists and engineers and their students. From the beginning, NSF recognized the importance of educating and training young people in science and engineering fields; improving and linking education and research continue to be a major priority and contribution of NSF. Of the \$3.5 million appropriated by Congress for the new Foundation’s first full fiscal year (from July 1, 1951, through June 30, 1952), NSF expended approximately \$1.07 million for 97 research grants and approximately \$1.53 million to award 535 predoctoral and 38 postdoctoral fellowships.

The new fellows were informed of their awards during the first week of April 1952. Among the predoctoral fellowship recipients, 154 were listed as first-year students, that is, college seniors intending to enroll in graduate school in the fall; 165 were completing their first year as graduate students, and 216 had completed two years or more. Arguably, these 573 fellowships, awarded to aspiring scientists and engineers in 47 states and the District of Columbia, composed the first widely visible indication that NSF was open and ready for business.

The first recipients of NSF fellowships made important contributions from many fields and sectors—both within science and engineering fields and outside of these disciplines. A short historical reprise of what the NSF fellowship meant to these first recipients shows that it helped many to decide to go into science, assisted in bolstering confidence, and made a significant difference in being able to choose their own areas of study. The first fellows included many who would later become prominent, such as Nobel Prize Winners Burton Richter and James Cronin, and Maxine Singer, a co-discoverer of recombinant DNA, now President of the Carnegie Institution of Washington and the 1999 recipient of the NSB's Vannevar Bush award. Also they included many who, although less prominent, have contributed to their fields; to government, industry, and academia; and to their communities.

The following excerpts are from a survey and report of the first fellows by William A. Blanpied, summarized in "The National Science Foundation Class of 1952" (Blanpied 1999). These excerpts give a flavor of the times as well as what the NSF fellowship meant to the careers and lives of these then young people—approximately 100 members of the NSF Class of '52 who responded to a personal letter. This group of scientists and engineers have had professional careers approximately spanning the lifetime of the Foundation, and their recollections of their fellowship years and the impacts of those years on their subsequent professional life provide insights into the personal impacts as well as societal impacts of supporting bright young scientists and engineers. The birth years of these respondents range from 1917 through 1932, the median year being 1929. Many experienced military service in World War II and noted that their undergraduate education had been made possible, at least in part, by benefits received from the GI bill of rights,⁴⁸ which had been enacted in June 1944. U.S. higher education was becoming democratized during their undergraduate years.

Peter von Hippel, among the youngest of the Class of '52, recalled classmates who were "given the GI bill of rights, often considerably older and more mature." Peter von Hippel was then in his last year of a five-year combined bachelor's/master's in science program in biophysics at MIT which he believes was the first undergraduate biophysics program in the country. Von Hippel is now the American Cancer Society Research Professor of Chemistry at the Institute of Molecular Biology at the University of Oregon.

Edward O. Wilson, now Pellegrino University Research Professor at Harvard and then a student in Harvard's Department of Biology, recounted the thrill of getting the news of the fellowship. "The announcements of the first NSF predoctoral fellowships fell like a shower of gold on several of my fellow students in Harvard's Department of Biology on a Friday morning in the spring of 1952. I was a bit let down because I wasn't among them, but then lifted up again when I

received the same good news the following Monday (my letter was late)."

Joseph Hull, a geology major at Columbia, recalled, "I knew that there were political implications when Senator Mike Monroney of my home state, Oklahoma, wrote me a congratulatory letter reminding me that he had voted for the bill. I was also aware that supplying geographical diversity by being from Oklahoma gave me an edge in the selection. No matter. I was exhilarated. Being an NSF Fellow carried a lot of prestige." Hull received his doctorate from Columbia in 1955 and then pursued a career with the petroleum industry.

Richard Lewontin, Professor of Biology at Harvard, had even earlier knowledge of NSF. "When I was a high school senior in 1946," he wrote,

I was in the first wave of Westinghouse Science Talent Search winners. One of the things that the group did when we went to Washington was to testify before a congressional committee that was considering the National Science Foundation legislation. As bright high school students, it was our task to tell a somewhat reluctant congressional committee that the Federal support of science through a National Science Foundation would be a good thing. I do not know if that testimony had any influence, but you may well imagine that I remember the occasion very well.

Josephine Raskind, later Peter von Hippel's wife, was a classmate of Lewontin's at Forest Hills High School and a co-Westinghouse finalist. She recalls meeting President Truman and physicist Lise Meitner, among others, on that 1946 trip to Washington.

At least three other members of the NSF Class of '52 had also been Westinghouse finalists. One was Alan J. Goldman, currently in the Mathematical Sciences Department of the Whiting School of Engineering at The Johns Hopkins University, who wrote that the multiday trip to Washington for the finalists was the first time he had been away from his family even overnight. Another was Andrew Sessler, now Distinguished Senior Scientist at the Lawrence Berkeley laboratory. The third was Barbara Wolff Searle, who reported that she was the "top girl" in that group in 1947. Searle was also among 32 women who received NSF fellowships in 1952. Remarkably, 5 of those 32 were seniors at Swarthmore College. "The men who took the exam were not slouches," Searle recalled, "but whatever the test tested, we (the women) did better at." Two other members of the Swarthmore-5 also responded to the November 1998 letter: Vivienne Nachmias, recently retired as Professor in the Department of Cellular and Developmental Biology at the University of Pennsylvania School of Medicine, and Maxine Singer, President of the Carnegie Institution of Washington. Searle herself recently retired from the staff of the World Bank, where she served for several years as an education specialist.

Joseph Berkowitz, who was working in the nuclear reactor program at Brookhaven National Laboratory when he received the fellowship that allowed him to pursue graduate work in chemistry at Harvard, had graduated from New York University as a member of the Class of 1951. "The opportunity to attend graduate school at Harvard opened entirely new

⁴⁸An Act to Provide Federal Government Aid for the Readjustment in Civilian Life of Returning World War II Veterans. Public Law 78-346, enacted June 22, 1944.

vistas for me,” he recalled. “My fellow students were quite different from the ones I encountered as an engineering student. I discovered the addiction to basic research. I had the opportunity to attend lectures by future Nobel Prize winners. It launched me on a life-long career in basic research, which I didn’t know was possible in my youth. It’s probably no exaggeration to say that the NSF predoctoral fellowship changed the direction of my life.” Berkowitz, who spent much of his career at Argonne National Laboratory, is now an Emeritus Senior Scientist at that facility.

Several respondents also noted that their fellowships allowed them to change their research directions. Burton Richter, Director Emeritus of SLAC and a Nobel Laureate in Physics, recalled that, as a student at MIT, he was working ...

on an experiment [at the National Magnet Laboratory] to determine the hyperfine structure of the radioactive mercury isotopes. My job was to make the radioactive mercury isotopes, which I did by a kind of inverse alchemy turning gold into mercury using the MIT cyclotron. I began to find myself more interested in what was going on at the cyclotron laboratory than in what was going on with my experiment. As my interest grew, I decided that perhaps I should change fields. I went off to spend three months at Brookhaven seeing what particle physics was like. I found I loved it and on return transferred to the synchrotron laboratory and began working in the direction that I have pursued ever since. It may be that I could have done all of this with a normal graduate research assistantship but it would certainly have been more difficult. I would have had to find a professor who was willing to spend his own research money to give a young student an opportunity to try out some different area.

Robert M. Mazo, a senior chemistry major at Harvard in the spring of 1952 and now Professor Emeritus in the Department of Chemistry and Institute of Theoretical Science at the University of Oregon, suggested that there were ...

two primary classes of people affected by the fellowship program. There were those like me, already intellectually committed to a career in science, but uncertain about practical ways and means [of financing their graduate education]. Then there were those, many with great abilities, which were unsure about their career aims. The existence of a fellowship program temporarily freeing them from financial stress tipped the balance in favor of a career in science for many.

“My NSF year,” as Swarthmore graduate Vivianne T. Nachmias recalled,

was primarily a year that allowed me to try things out, to search, to take more graduate studies, and so to narrow my field of interest. I had the fixed idea that the only thing to study was the brain. But how? After my year with NSF support [in the Harvard Department of Chemistry], I went across the river to Harvard Medical School and there in the first year, I encountered cells, in my histology course with Helen Padykula as instructor. I did my first successful project with her (on muscle cells) and from then on I was as interested in cells as in the brain.

Nachmias went on to earn a medical degree from the University of Rochester in 1957 and subsequently pursued a career in biomedical research. She conjectured that another reason for her decision to pursue a medical degree rather than a doc-

torate may have been that “at that time there was only, to my knowledge, one woman professor at Harvard, and she, a very successful astronomer, was from Russia.”⁴⁹ One indeed might conclude that there was not much chance of success along traditional graduate lines. On the other hand, one did see practicing physicians, though admittedly not many. The current scene is one of women succeeding in biology all over the place.”

A few of the first fellows reported that, although they had entered graduate school intending to pursue careers in industry, their fellowship years convinced them to turn to academic careers instead. In contrast, George W. Parshall recalled that:

the academic progress and the financial freedom afforded by the fellowship gave me the liberty to explore a career in industry through summer employment. With the concurrence of my advisor, I accepted an offer from the Chemical Department of the DuPont Company to spend the summer of 1953 at their Experimental Station in Wilmington, Delaware. That summer was an eye-opener! I was assigned to work with a team of chemists who were exploring the chemistry of a newly discovered compound, dicyclopentadienyliron, later dubbed ferrocene.

That experience also convinced Parshall to pursue a research career with DuPont after receiving his doctorate from the University of Illinois in 1954.

Certainly many of the recipients benefited personally, and most continue to be grateful for the opportunity given them almost one-half century ago. Harry R. Powers, Jr., who received his doctorate in plant pathology from North Carolina University in 1953 and has recently retired after his career with the U.S. Forest Service, recalled that, in the spring of 1952,

I was in the second year of my Ph.D. program. However, my family had quite a few medical bills that year, and as was usually the case, we had no medical insurance. I could see no way out except to leave school and get a job. Fortunately, our department head had encouraged all of the graduate students to take the test, a hard 8 hours as I recall [the Graduate Record Examination, the primary basis for the selection of fellows during the first year]. When the telegram came saying that I had received the award, I canceled plans to drop out of school since the fellowship provided more than I had been getting.

Responses from several members of the Class of ’52 expressed gratitude to NSF for having helped them launch their careers in science and engineering, a few regretting that they had not done so years earlier. Daniel Lednicer, who received his doctorate in chemistry from Ohio State University in 1954 and went on to pursue a career as a research chemist at the National Cancer Institute, was among those who decided not to wait—and to go straight to the top at that. “Sometime in the spring of 1954,” as he recalled,

renewal of the NSF fellowship for a third year came through. I was wakened bright and early on the morning following the

⁴⁹Nachmias was probably referring to Ceceilia Helene Payne-Gaposchkin, originally from the United Kingdom and a protege of Harlow Shapley; her husband Serge was a White Russian immigrant who worked at the Harvard College Observatory as an astronomer also.

party to celebrate the event by a reporter from the *Columbus Dispatch*. I must have been less than sharp in answering his questions. That renewal did make me realize that it would be appropriate to thank someone for this generous support of my graduate studies. The man who had proposed NSF and steered the bill through Congress was none other than the immediate past President, Harry S Truman, a man whom I admired even back in 1954. So a letter expressing my appreciation went off to him that summer. A letter in an expensive looking envelope with a Kansas City return address arrived in early October.

Lednicer made available a copy of that letter, whose tone is quintessentially Trumanesque:

October 2, 1954

Dear Mr. Lednicer:

Your good letter of September 21 was very much appreciated.

I always knew that the Science Foundation would do a great amount of good for the country and for the world. It took a terrific fight and three years to get it through the Congress, and some smart fellows who thought they knew more than the President of the United States tried to fix it so it would not work.

It is a great pleasure to hear that it is working and I know it will grow into one of our greatest educational foundations.

Sincerely yours,

/s/ Harry S Truman

One thing that is obvious is that the past 50 years' investments in research and education have been an excellent investment in people, ideas, and tools. It is hoped that the next 50 years will be equally as productive and exciting.

Enduring Themes: Continuity and Change

The 1948 and 1998 speeches delivered by Presidents Truman and Clinton, compared and contrasted in an earlier section, qualify as significant indicators of the science policy priorities of those respective presidents. But presidential addresses are rare and subject to time constraints. As a result, only the most essential of their priorities can be presented in public forums.

A comparison of other documents from the 1940s and the current time of transition reinforce a conclusion reached in comparing the speeches made by President Truman and by President Clinton 50 years later: namely, that whereas there is an enduring quality to the science policy themes articulated a half-century ago, changes have also occurred within those overarching themes. In some cases, issues associated with a particular theme have not changed a great deal. In other cases, the character of the issues are very different, reflecting the largely unpredictable changes that have occurred both as a result of advances in science and engineering, and in the social, political, and economic contexts in which science and engineering activities take place.

Examples of the enduring character of many science policy

themes, along with changes in emphasis, can be discerned by comparing some of the principal themes presented in *Science—The Endless Frontier* and *Science and Public Policy* with those presented in *Science in the National Interest* and *Unlocking Our Future*, in addition to those discussed in greater detail in subsequent chapters of *Science and Engineering Indicators – 2000*.

Support and Performance of R&D

National R&D Expenditures

Science and Public Policy included data on estimated U.S. R&D expenditures for 1947 (Steelman 1947, vol. I, 12, table II). (See text table 1-3.) The approximately \$1.2 billion expended during that year was a record high. Nevertheless, the report argued that a national research program that would be adequate to address the Nation's needs would require that those expenditures double by 1957 so that they would then constitute 1 percent of national income (that is, GDP).

Today, total national R&D expenditures for 1998 were estimated at \$220.6 billion, or 2.61 percent of GDP.⁵⁰ (See chapter 2.)

Sources of R&D Expenditures

Science—The Endless Frontier included pre-World War II data on sources of national R&D expenditures (Bush 1945a, 86), and *Science and Public Policy* included similar data for 1947 (Steelman 1947, vol. I, 12). According to the former, industry accounted for almost 68 percent of total national R&D expenditures in 1940, with the Federal Government accounting for about 19 percent, universities for 9 percent, and other sources for about 4 percent. (See text table 1-3 and figure 1-2.) During World War II, the Federal Government became the dominant supporter of R&D, a condition that continued during the early postwar years. In 1947, according to the Steelman report, the Federal Government accounted for approximately 54 percent of national R&D investments and industry for about 40 percent, with universities and other sources each contributing less than 4 percent. (See text table 1-3.)

After the end of World War II in 1945, industrial R&D investments increased, while Federal expenditures declined so that by the end of the decade industry was once again the leading supporter of R&D in the country. The Korean War, which began on June 25, 1950, a few days before the start of FY 1951, led to a rapid increase in defense R&D expenditures so that, beginning in 1951, Federal contributions exceeded those of industry. That situation continued until 1980, when industrial R&D investments equaled and then began to exceed those of the Federal Government. (See text table 1-3 and figure 1-2.) Since 1990, Federal R&D expenditures measured in constant dollars have declined, while those of industry, universities and colleges, and other sources have continued to increase. In 1998, industry accounted for 65.1 percent of

⁵⁰Because U.S. Government accounting conventions changed during the early 1950s, precise comparisons of current R&D expenditure levels with those in the 1940s and earlier are difficult to make. (See footnote 43.)